3, 2, 1 BLASTOFF: ANALYZING DATA THROUGH ROCKETRY

by

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ABSTRACT

The purpose for writing and submitting this manuscript to the National Council for the Teachers of Mathematics (NCTM) is to encourage other teachers to include more "hands-on" integrated activities into the courses of their mathematical teachings. Mathematics often gets criticized for its paper and pencil approach to teaching the basic concepts and for using the story problem to provide an application for those basic skills. Through the publication of this article, this writer hopes to encourage other mathematics teachers to "think big" and provide realistic and authentic outlets for mathematical investigation and integration. This instructor has a number of lesson plans that motivate students to think, solve problems and discover mathematics for themselves. Hands-on activities do present challenges for the teacher in the areas of communication, questioning and evaluation (Stupiansky & Stupiansky, 1998). After trying many types of

activities, the instructor has found that when students are challenged with an opportunity to use their creative as well as critical thinking skills, they are more engaged in the activity at hand and therefore demonstrate a better understanding of the mathematical concepts being covered. DeGeorge and Santoro (2004) stated, "Hands-on educational experiences move students beyond the traditional and passive practices of teaching and learning by incorporating creation, expression, and the presentation of ideas. Spectacular results can be achieved when learning is taken off the chalkboard and literally put into the hands of the learners themselves" (p. 28).

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Middle school students always seem to be amazed by seeing things fly. Whether students are watching the space shuttle or NASA launch a rocket, or their own shooting of rubber bands or the flying of paper planes or paper footballs, students seem to be intrigued with flight. Taking this natural interest, the instructor decided to combine their interest in flight with the application of math by introducing a water bottle rocket unit. When the average middle school student is confronted with launching water bottle rockets, many questions arise. What makes water bottle rockets fly? Can the rockets go higher? Why don't all bottle rockets reach the same height? Launching bottle rockets is an activity that catches the interest of all students and keeps them involved. Rocketry allows students to stretch their imagination and brings personal interest by allowing students to see their water bottle rocket actually fly. What is significant about this activity is that the students hypothesize what they think will occur at the outset, and then as they complete the activity they answer many of their own questions themselves by collecting their own data, making their own charts, graphing and interpreting their data.

In the rocketry activity, many of the activities students are engaged in help them learn the very same topics/objectives addressed in the eighth grade standards found in *Principles and Standards for School Mathematics* (NCTM 2000). The instructor believes that when students have a direct involvement in collecting data for themselves and are able to use a hands-on approach, students will take more of an interest in mathematics. A study conducted by Rockwell (2002) suggests that hands-on projects are an effective means of teaching a standard-based curriculum and that students develop both a greater appreciation for and understanding of what they are learning.

As the class began their rocketry unit, the excitement was contagious as students begin to predict what would happen, constructed their personal rockets, and collected the data needed for graph development.

Cross-Curricular Applications

For quite some time now, the educational arena has supported cross-curricular or integrated activities as a means of enriching the academic understanding of the adolescent learner. Caskey and Ruben (2004) stated cross-curricular teaching as essential, "When teachers and students select essential concepts to investigate and explore deeply, the students develop more meaningful connections with the curriculum. Throughout the academic year, integrated units of study and project-based learning help to connect students' efforts with real life" (p. 37). Retention of subject matter over time has also been documented. In a Quasi-experience done by Merrill (2001) on the integration of mathematics, science and technology he concluded that although there were no statistical significant increases in retention through his study, students did continue to exhibit cognitive learning gains two to four weeks after his instruction. Many activities that can be used in mathematics can also have a direct connection to other curricular areas. The rocketry activity certainly has a direct tie with certain areas of science. In this particular activity, students eventually discover that Newton's Third Law of Motion plays an important factor in the height of the rockets. In addition, the rocketry activity can also be integrated into Language Arts, as students write and present their findings, and with technology, a great application for the data gathering and graph preparation. As you will see later, this activity can also be adapted to high school level courses; but as a starting point for analyzing data and making graphs at the middle school level, the use of water bottle rockets is ideal.

Throwing a curve at linear functions

Linear functions and scatter plots are commonly taught in middle school math courses and are part of *Principles and Standards for School Mathematics* (NCTM 2000) which states that students need to transfer among mathematical representations to solve problems. In most traditional classrooms, the objective is usually accomplished by a student seeing a function and then being told to graph it using a number of ways, (Point slope form, x-y intercepts, or using the standard y=mx +b form). The reverse is also true. Students are often given a line and asked to find the equation of that line. Many middle school students leave their education thinking that everything must somehow come out to be a linear function and are unable to recognize the transfer between the equation and the graph. Research shows that teachers, and the mathematical emphasis in textbooks, do not place enough focus on the transfer between algebraic, numerical and graphic representation of linear functions and other types of non-linear functions at the middle school level. Yerushalmy and Gafni (1992) stated that "Functions in its multiple representations is the fundamental object of algebra which ought to be presented through the learning and teaching of any topic in algebra" (p.318). Knuth (2000) pointed out the importance of students being able to transfer between representations and the importance its play in the students understanding of these functions. Math teachers need to show their students graphs of non-linear functions as well as linear and how they are represented in the form of a graph as well as algebraically. For example, teachers could show students how compounded interest looks in the form of a graph as well as its equation and plot points to find out how the graph changes over time. After talking about linear equations and functions, students may have a surprised look on their face. By showing both linear and nonlinear functions in graph form, teachers will bring to life the idea that not every mathematical relationship is represented by a straight line.

Classroom Activity

On the first day of this activity the instructor asked the students to write down, in their math journals, their comparison of a 20 ounce plastic soda bottle to that of a rocket. Students recorded many responses but the most common and obvious one was that both objects were both cylindrical in shape and had the same basic aerodynamic design if there would be a cone on the top (or bottom). As a part of their explanation, most students turned their water bottles upside down. When asked why, students usually responded that "this end is where the exhaust from the fuel comes out". Their responses were a perfect setup for the next task. It was then explained to the students that we were going to fill their 20 ounce bottles with varying amounts of water and use an air compressor to shoot them off, similar to rocket launching. After presenting the overview for our experiment/activity, the students were asked to write in their math journals which water bottle rocket(s) they thought would go the highest and why. The instructor then added to the task by asking students to include a graph of their predictions, using weight on one axis and height on the other (see Figure 1).

As the instructor had predicted, after just spending time on linear equations and functions, many student's predictions/expectations were reflective of a constant equation and their graphs were of a linear nature. Some students had the rockets going higher (positive relationship) as the weight (water) increased and others showed a negative relationship on their graph. When the instructor asked some of the students why their graph showed a positive relationship, many responded with comments similar to, "I thought that the amount of water in the bottle would act like fuel for the rocket" whereas the ones that showed a negative relationship based their assumption on the total weight of the rocket. The lighter the rocket, the higher it would go. One thing common in the student's responses, was the thought that although they knew the weight of the rocket (from 0-20 ounces), they just guessed at the height the rocket would reach. Some students thought that their rocket would only reach a height of 10 feet while other students thought their rocket would go as high as 100 feet.

On the second day, each student was assigned a different amount of water to put in his/her bottle and students were asked to find a means to measure their assigned amount. Measuring cups were provided, which many of the students used by conversion (8 ounces equals 1 cup, 4ounces equals one-half cup etc.) and students filled their bottles accordingly. The conversion method proved easy for the student who had an "even" amount of water to fill their bottle, but the student who had an "odd" amount struggled with finding an accurate measurement. The class discussed how they could find an "odd" amount of water, given only "even" measuring units. The students came to the conclusion that they "need only find a means to measure one ounce". The instructor asked how they would do this. Looking around the room one student responded, "there are some Dixie cups over there, so if we fill the ¼ cup measuring cup and pour it evenly into four of the Dixie cups, we should have one ounce in each cup". The thought process was good, but the mathematics behind it wasn't. Another student then said, "Shouldn't you do it with a ½ cup since ½ cup equals 4 ounces and then each Dixie cup would have one ounce in them?" After the class concluded that this would be the best way to measure their "odd" amount bottles, they sat down and brainstormed what data should be collected, the following day when they would launch their rockets. The students generated three pieces of data that they thought would be important: the height reached by their rocket, the time it took the rocket to the peak, and the total flight time. Students were then assigned to prepare a table for the launches.

On launch day, two groups of students measured the angle of elevation (in order to go back into the classroom and figure out the height). One group placed themselves a distance of 212 feet away from the launch pad, while the other group placed themselves 120.5 feet away from the launch pad. Students took two measurements from these distances and then used the average. To find the angle of elevation we used a gravity protractor taped to a meter stick and an altitude finder.

Two students with stopwatches recorded the time it took the rocket to reach its peak height and the total flight time (from when the rocket was launched to when it hit the ground) (see Figure 2). After each rocket was launched, the times and angles where yelled out and each student recorded the times and measurements on their tables in their math journal.

Bringing the data back in the classroom

The next phase involved analyzing the data collected (see Figure 3). Students took the data that they collected back into the classroom to find out if the height of the rocket had a constant relationship to how much water was in the rocket, as most students predicted. In the process of data analysis, students had some trouble figuring out the height at which their rockets peaked. Many students said that they needed more information, i.e. "How far away were group 1 and group 2 from where the rocket reached its peak height, so we can use the Pythagorean Theorem?" The students did realize they couldn't measure that distance, but many were insistent on using the Pythagorean Theorem, because up to this point it was the only way that they knew of to find the sides of right triangles. This was the perfect opportunity to introduce right triangle trigonometry functions:

Sine = opposite/hypotenuse

Cosine = adjacent/hypotenuse

Tangent = opposite/adjacent

Students formed a human triangle and then the students at the vertices pointed to the students "opposite" them and to the students "adjacent" to them. Students quickly realized that "opposite" and "adjacent" was dependent upon which vertex they were at. Students made the connections between the angle of elevation, the height of the rocket, and the distance away from the launch pad to solve the tangent function for the height of the rocket (see Figure 4). Students then added this data to their table in their math journal (see Figure 5).

Analyzing and Graphing the Data

Using the data the students collected, they made three different graphs: height vs. ounces, maximum height time vs. ounces, and total flight time vs. ounces (see Figure 6).

After completion, students looked at their graphs and noticed that they were not linear. The graphs showed no relationship, positive or negative, and they determined it would be hard to put a "line" of best fit through the points. Based on their graph analysis, students were assigned to record conclusions in their math journals. Many student entries written were similar to this, "After examining my graph of the average height, I did not see a pattern except that all the readings were between 30 and 105. I also saw that the readings start lower, go up, and then come way back down".

Conclusion

By launching the rockets, students had the opportunity to see first hand how high their rocket went and whether their conjecture was correct. Although this may not have been the most accurate experiment with water bottle rockets, due to the instruments that we used to find the height, the students still experienced a sense of accomplishment and satisfaction. Students realized that there were many factors that came into play when launching the rockets, (aerodynamics, pressure, wind, angle of launch, mass, exhaust, etc.) but the activity itself built a strong foundation for working with many mathematical concepts (slopes, graphs, conversions, Pythagorean theorem, right angle trigonometry, nonlinear functions, equations etc.). The rocketry activity also opened the door as a means of connecting math to other curricular areas as well as real life applications.

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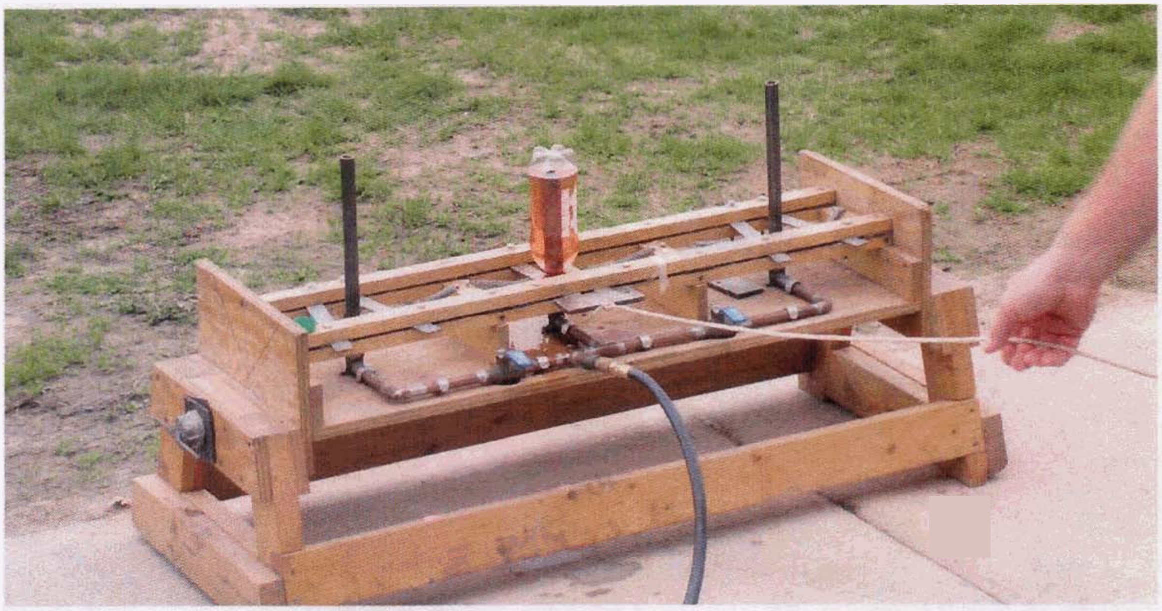

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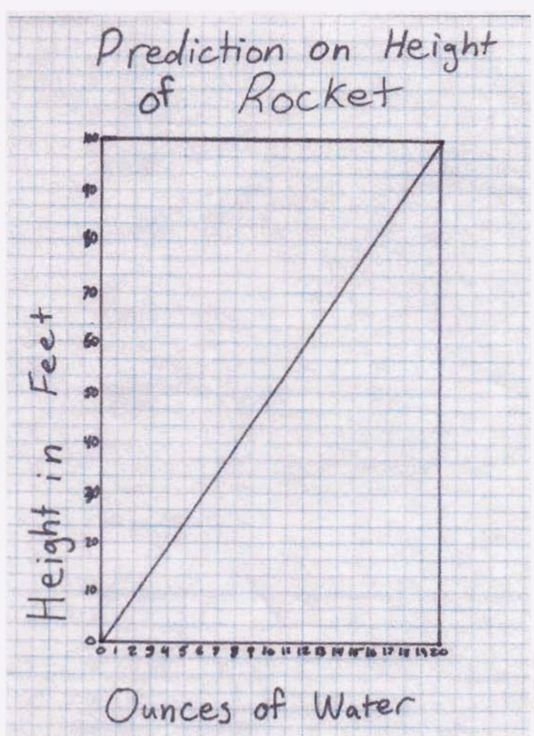

Figure 1. This graph is an example of what the students made when asked to predict the height of the rocket with different amounts of water.

Figure 2. A group of students timing the flight of the rocket, finding the height of the rocket using an altitude finder, and recording the data.

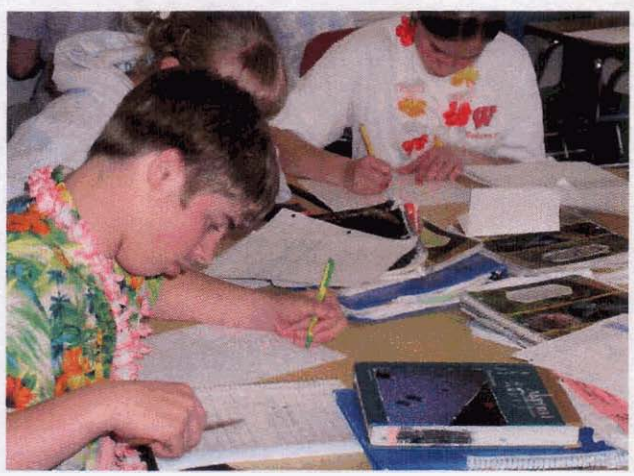

Figure 3. Students analyzing data collected.

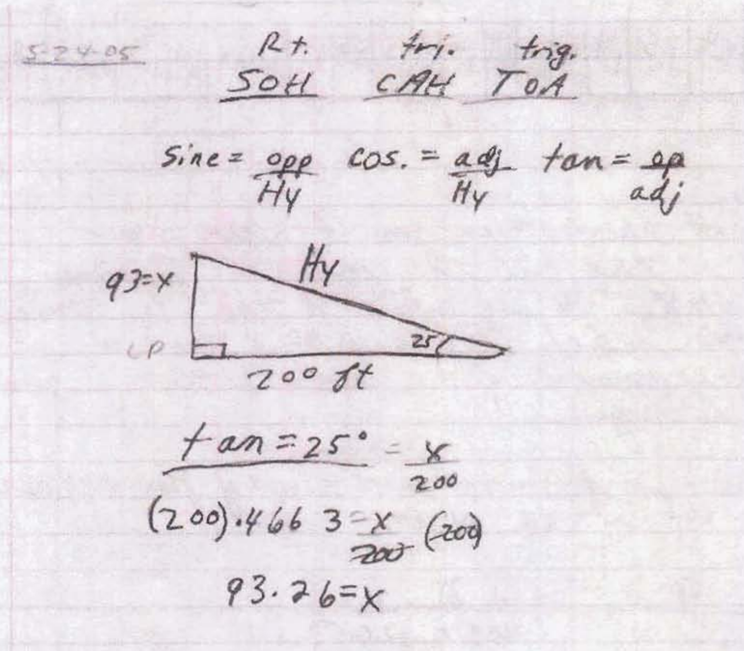

Figure 4. Notes taken from a math journal showing the right triangle trigometric functions.

Ounces	0	1	2	3	4	5	6	7
Angle of Elevation (Degrees)								
Seth	none	25	16	25	26	21	26	30
Jackie	32	30	25	21	29	28	28	35
Air Time (Seconds)	4.4	4.7	4.9	4.2	4.4	4.8	4.7	4.6
Peak Air Time (Seconds)	2.1	1.4	1.4	1.5	1.4	1.3	1.3	1.4
Height (Feet)								
Seth	None	98.9	60.8	98.9	103.4	81.4	103.4	122.4
Jackie	75.3	69.6	56.2	46.3	66.8	64.1	64.1	84.4
Average	75.3	84.3	58.5	72.6	85.1	72.8	83.8	103.4

Figure 5. A table completed by one student, using the computer.

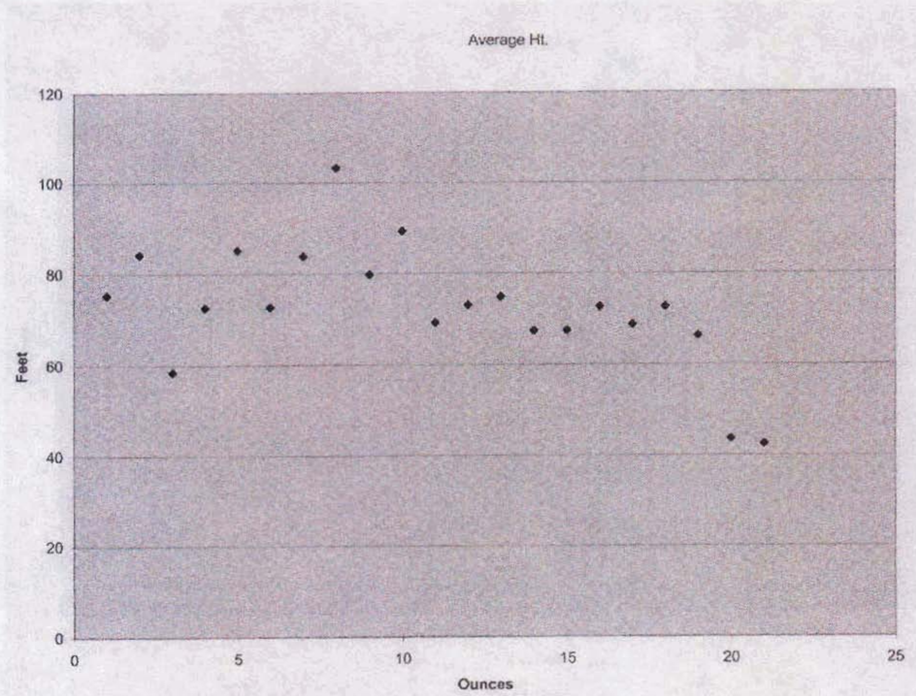

Figure 6. A computer generated graph of the average height of the rocket versus the amount of water in the bottle.

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